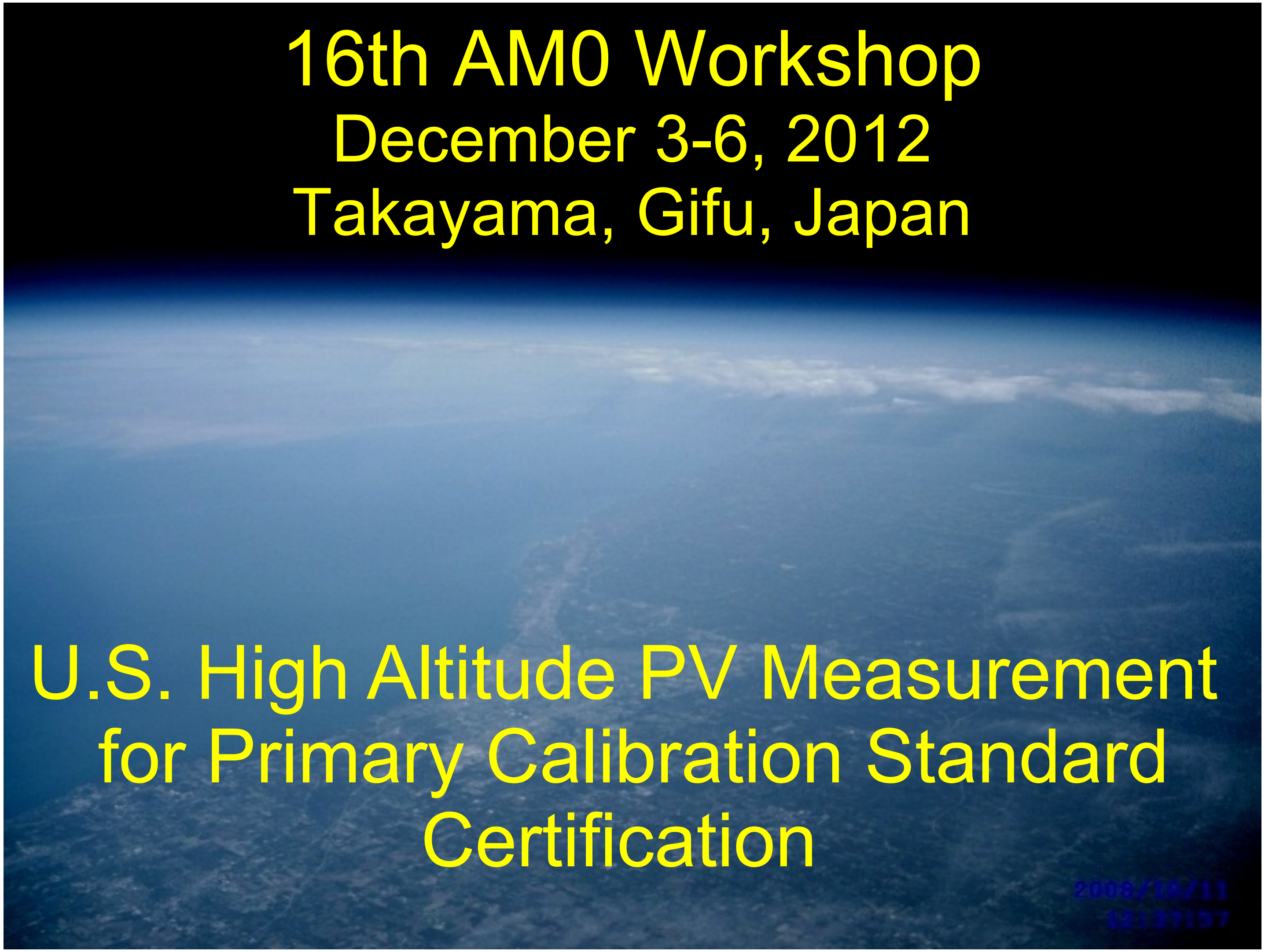
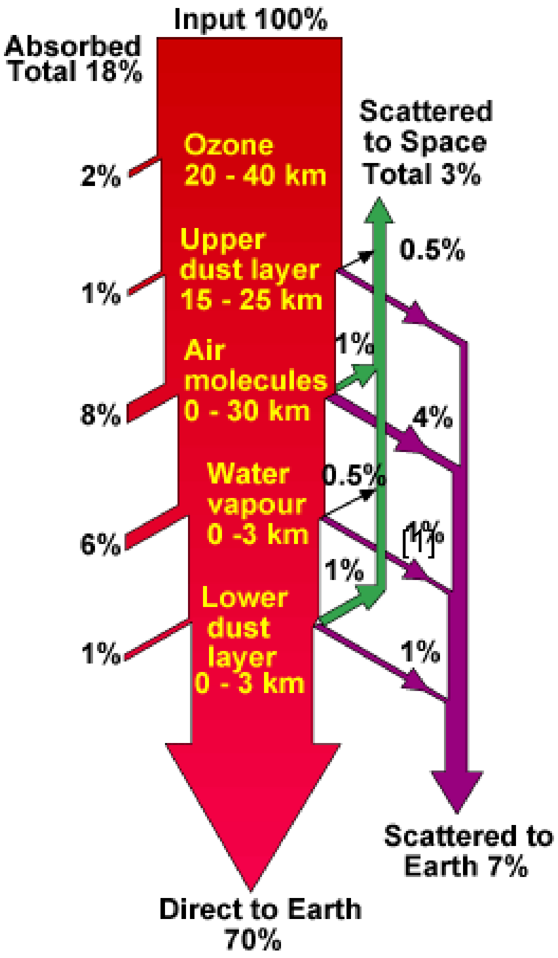

16th AM0 Workshop
December 3-6, 2012
Takayama, Gifu, Japan
U.S. High Altitude PV Measurement for Primary Calibration Standard Certification

Overview

- Background
- Current Capability
- Future Options
- Comparison of Learjet 25 and ER-2 Platforms

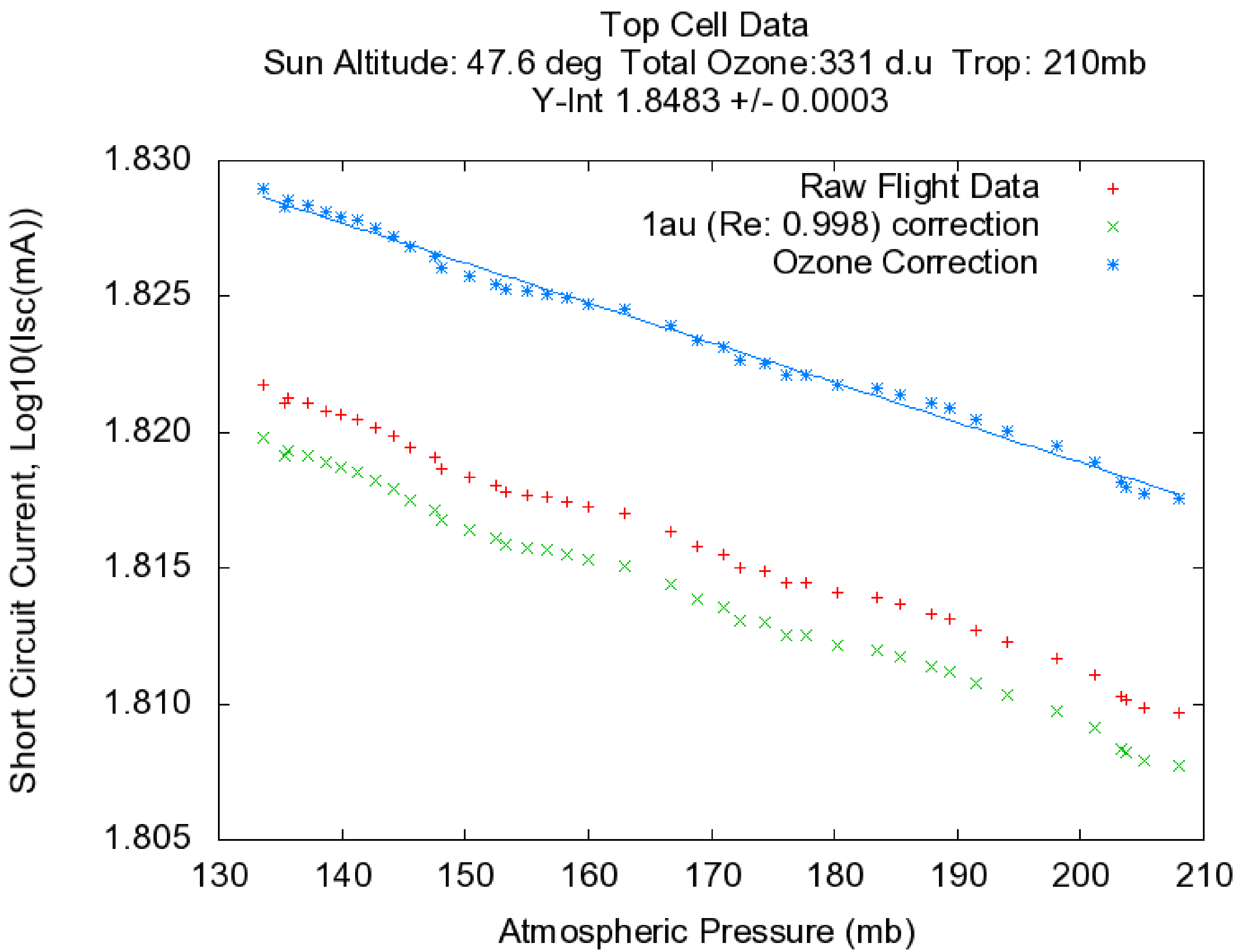
Background



- AM0 primary calibration standards are required to calibrate laboratory solar simulators for measurement of space PV cells
- Ideally calibrations standards would be measured using a helium balloon platform above all but negligible absorbing and scattering components of the atmosphere (120,000 ft./36.6 km)
  - Maintaining funding for balloon measurement platforms have been problematic
- Currently U.S. standards are measured on board aircraft flying at the ceiling of their flight envelopes.
  - This method requires correction for ozone for 3J cells

Atmospheric Correction

- Isc data is corrected for current earth-sun distance and ozone levels.
  - Ozone correction based on satellite measurements of total ozone column density and a pressure dependent distribution model.
- Air Mass number calculated from pressure and sun declination angle.
  - Sun angle change is negligible during a 20 minute flight at local noon.
  - Pressure can be used directly.



Langley Plot Generated - Semi log plot of Isc vs. Air Mass is fit linearly and AM0 Isc extrapolated

Current Capability – Learjet 25

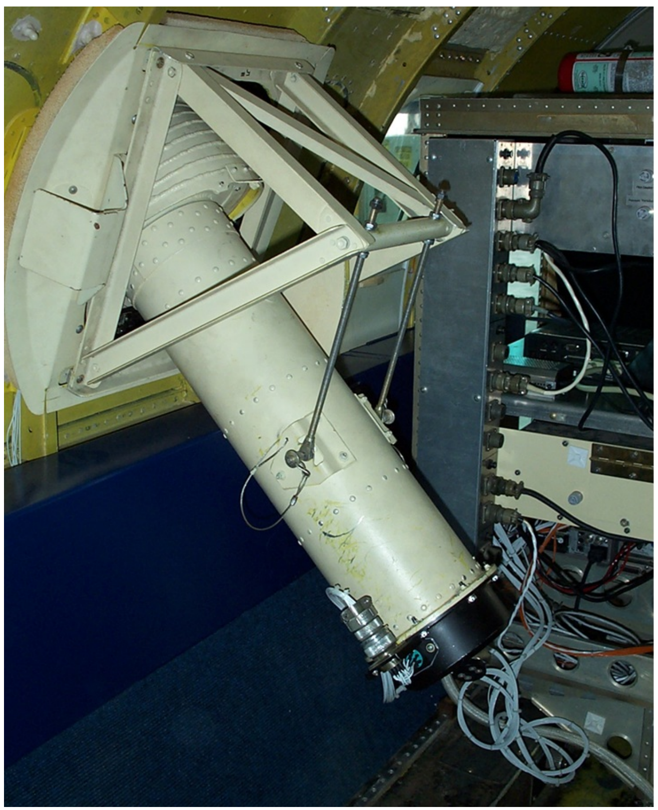
- Based at NASA – Glenn Research Center (GRC) Cleveland OH
- High Altitude testing has been conducted since 1963
- Operational Ceiling – 45,000 ft. (13.7 km) – 50,000 ft. (15.2 km) ASL
- Good correlation with balloon (1J, 3J) and shuttle tests (1J)
- Standard deviation in Isc (AM0) ~ 0.75% for top cell, ~ 0.5% for middle and bottom cell
- Isc measurement for all cells, I-V curve for limited number of cells

Method – Flight Plan

- Fly along 45th Parallel
- Ascend to 48,000 – 50,000 ft. (14.5-15 km) ~AM 0.2
- Data collection starts at local solar noon ± 10 min
- Descend at 1000-1500 ft./min (300-450 m/min) to 30,000-35,000 ft. (9 -11km) while collecting data

Collimating Tube and Cell Fixture

- Temperature controlled within ±1°C
- Angle can be set between 20-50° from horizontal



Sun Sight

- Enables aircraft pilot to align collimating tube with sun
- Sight is calibrated to tube prior to flight

Future U.S. Capability Options

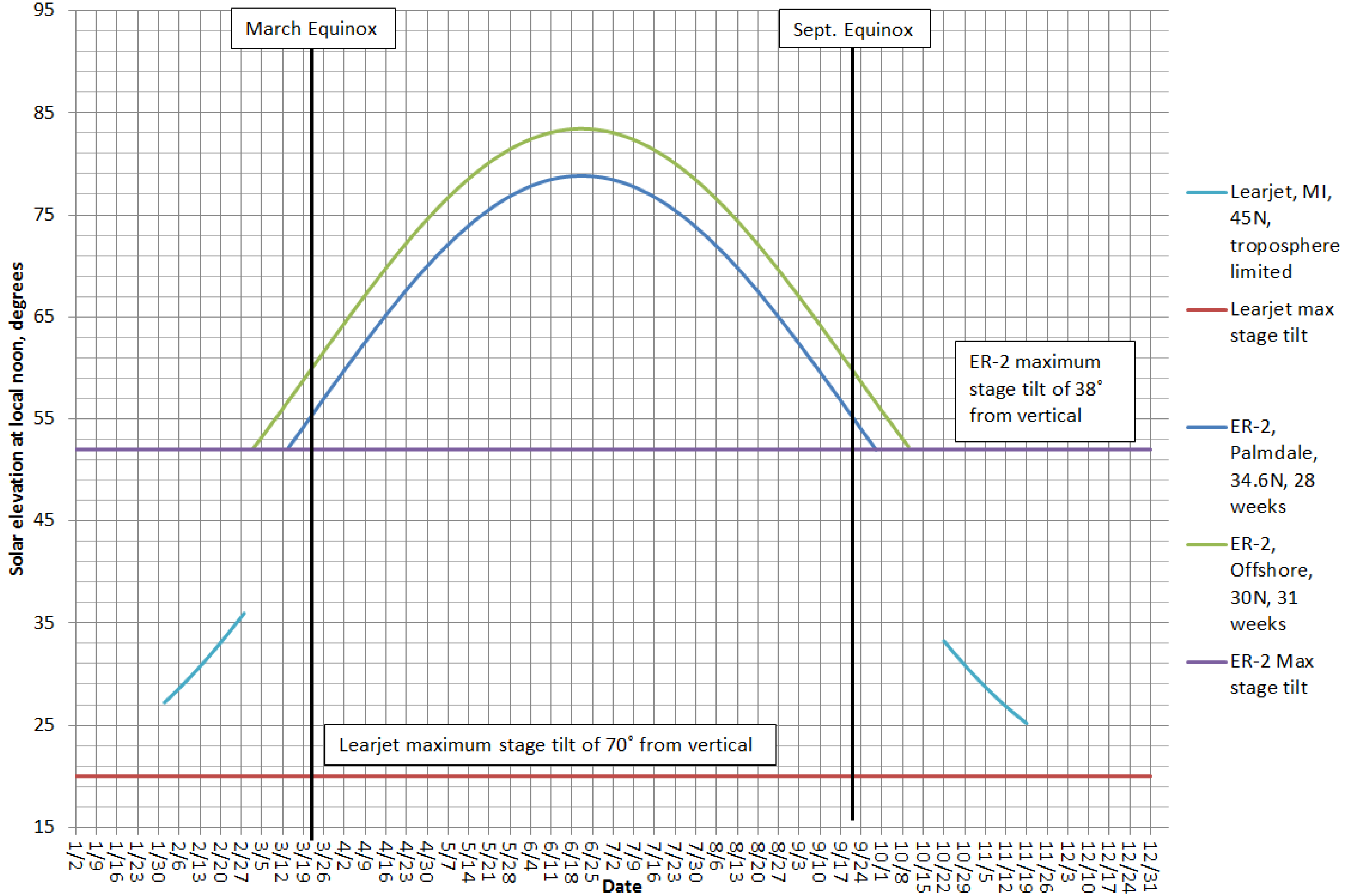
- NSCAP Balloon
  - NASA and DOD joint effort
  - Not currently funded

- NASA ER-2 High Altitude Aircraft – Dryden Flight Center
  - Under consideration

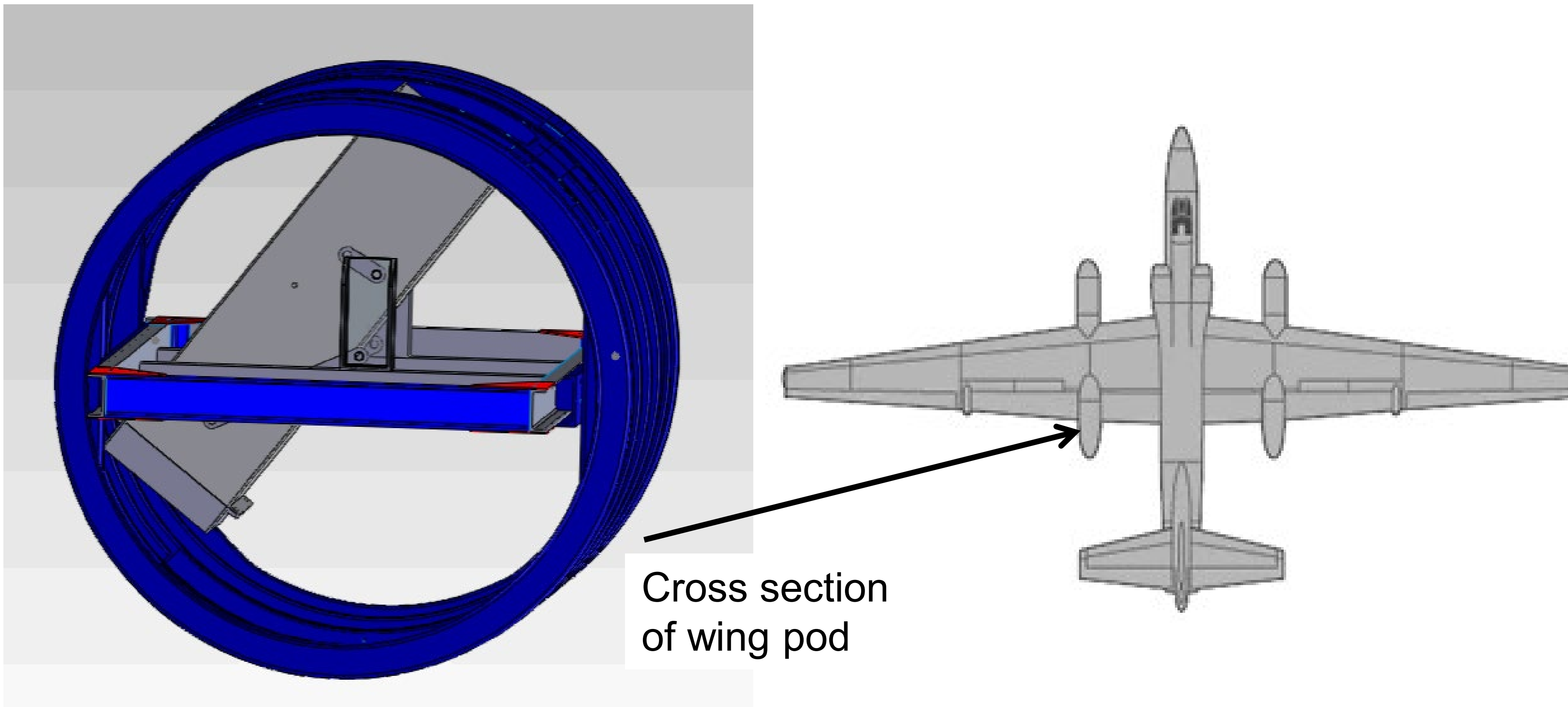
ER-2 Overview

- The ER-2 AMO project would use NASA's ER-2 high altitude aircraft as a platform for solar cell measurements.
- The ER-2 can fly significantly higher (65,000 ft. vs. 48,000 ft. (19.8 km vs. 14.5 km)) than the Learjet-25.
- ER-2 flight parameters would compliment the Learjet 25 flight season and extend the overall testing season.
- Uses similar hardware and methods as the Learjet to accomplish the same goal – Obtain AM0 performance data on solar cells.
- ER-2 would reduce the degree of ozone correction required and thus improve upon uncertainty for data collected at lower altitudes.
- Larger measurement stage area allows for increased size or number of samples.
- Use of 2 wing pods is a possibility.

Normal flight opportunities for Learjet and ER-2 platforms



Concept of Collimation Tube Design



38.2˚ maximum angle from vertical
3:1 length to diameter collimation ratio

Comparison of ER-2 and Learjet Platforms

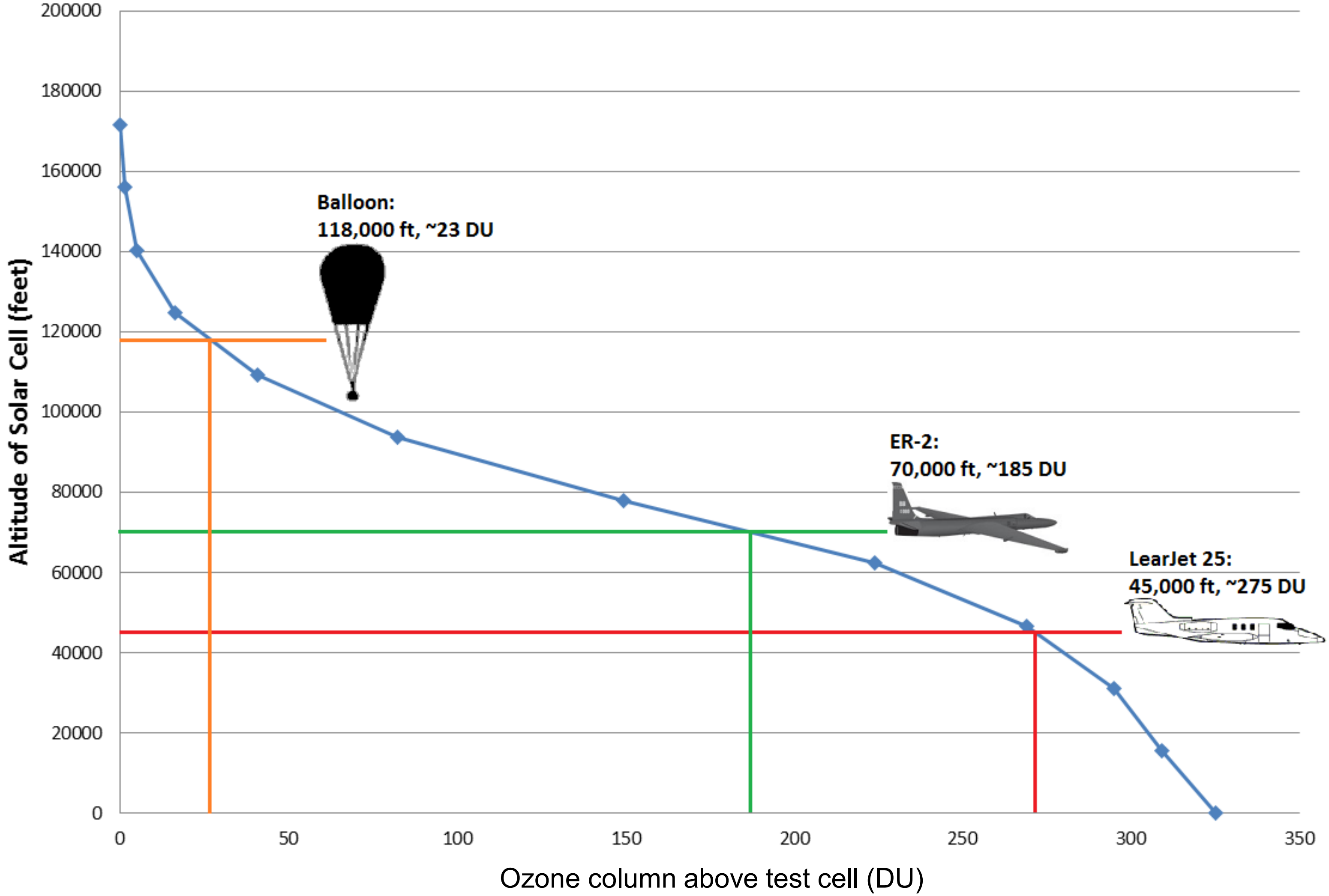
- Preliminary cost analysis indicates that costs per standard will be similar for either platform under certain conditions

- Factors that affect standard measurement costs per piece
  - Number of cells being measured
  - Number of flights required
  - Time of year

Cell capacity comparison

flight platform	Test area, cm	NSCAP 2 x 2 population	NSCAP 4 x 8 population	NSCAP 8 x 8 population	large area, 15.24 x 15.24 population
Learjet -25	11.4 Ø	6	2	1	0
ER-2 one pod	18.6 x 18.6	16	4	1	1
ER-2 two pods	2 x 18.6 x 18.6	32	8	2	2

~33% Reduction in Atmospheric Ozone vs. Learjet



Atmospheric Correction

Present Lear Analysis suggests Langley Plot extrapolation will be valid for ER2

- Less extrapolation (<½ air mass)
- Still need to correct for ozone
- Water vapor may be more of an issue for increased junctions
  - Need 4J tests/analysis
  - Need 6J tests/analysis (UV (ozone) and IR (water)
  - Smaller bandwidth increases sensitivity to absorption bands (O2, H20, O3)
  - Correction methods may be developed

Other NASA GRC PV Measurement Capabilities

- Triple source (xenon arc/tungsten filament/filtered tungsten filament) solar simulator
- Spectral response measurement
- Thermal cycling measurement
- Large area I-V curve measurement
- High concentration I-V curve measurement
- Low temperature I-V curve measurement
- Low intensity illumination measurement

NASA